

Chapter 13 Grounding Systems

13-1. General

a. Purpose. A safe grounding design has two objectives: to carry electric currents into earth under normal and fault conditions without exceeding operating and equipment limits or adversely affecting continuity of service and to assure that a person in the vicinity of grounded facilities is not exposed to the danger of electric shock.

b. Reference. IEEE 142, known as “The Green Book,” covers practical aspects of grounding in more detail, such as equipment grounding, indoor installations, cable sheath grounding, etc. This standard provides guidance in addressing specific grounding concerns. Additional guidance for powerhouse-specific grounding issues is provided in EPRI EL-5036, Volume 5.

13-2. Safety Hazards

The existence of a low station ground resistance is not, in itself, a guarantee of safety. During fault conditions, the flow of current to earth will produce potential gradients that may be of sufficient magnitude to endanger a person in the area. Also, dangerous potential differences may develop between grounded equipment or structures and nearby earth. IEEE 80 provides detailed coverage of design issues relating to effective ground system design. It provides a detailed discussion of permissible body current limits and should be reviewed prior to developing a grounding design. It is essential that the grid design limit step and touch voltages to levels below the tolerable levels identified in the standard. The conditions that make electric shock accidents possible are summarized in Chapter 2 of the guide and include:

a. High fault current to ground in relation to the area of ground system and its resistance to remote earth.

b. Soil resistivity and distribution of ground currents such that high potential gradients may occur at the earth surface.

c. Presence of an individual such that the individual’s body is bridging two points of high potential difference.

d. Absence of sufficient contact resistance to limit current through the body to a safe value.

e. Duration of the fault and body contact for a sufficient time to cause harm.

13-3. Field Exploration

After preliminary layouts of the dam, powerhouse, and switchyard have been made, desirable locations for two or more ground mats can be determined. Grounding conditions in these areas should be investigated, and the soil resistance measured. IEEE 81 outlines methods for field tests and formulas for computing ground electrode resistances. Sufficient prospecting should be done to develop a suitable location for the ground mat coupled with a determination of average soil resistivity at the proposed location. IEEE 81 describes and endorses use of “the Wenner four-pin method” as being the most accurate procedure for making the soil resistivity determination. It also provides information on other recognized field measurement techniques.

13-4. Ground Mats

a. General requirements. The measured soil resistivity obtained by field exploration is used to determine the amount of ground grid necessary to develop the desired ground mat resistance. The resistance to ground of all power plant, dam, and switchyard mats when connected in parallel should not exceed, if practicable, 0.5 ohm for large installations. For small (1500 kW) plants, a resistance of 1 ohm is generally acceptable. Practical electrode drive depth should be determined in the field. A depth reaching permanent moisture is desirable. The effective resistance of, and the step and touch potentials for, an entire ground mat with a number of electrodes in parallel can be determined from IEEE 80. The diameter of the electrode is determined by driving requirements. Copper-weld ground rods of 3/4 in. diam are usually satisfactory where driving depths do not exceed 10 ft. For greater depths or difficult soil conditions, 1-in.-diam rods are preferred. Galvanized pipe is not suitable for permanent installations.

b. Location. The depth and condition of the soil upstream from the dam on the flood plain is frequently favorable for placement of one or two ground mats. These can be used for the grounding of the equipment in the dam and leads extended to the grounding network in the powerhouse. At least one ground mat should be provided under or near the switchyard.

c. Leads. Leads from ground mats should be sufficiently large to be mechanically durable, and those which

may carry large fault currents should be designed to minimize IR drop. Two leads, preferably at opposite ends of the mat, should be run to the structure or yard, and the entire layout designed to function correctly with one lead disconnected. The design and location of connecting leads should account for construction problems involved in preserving the continuity of the conductor during earth moving, concrete placement, and form removal operations.

d. Types of ground mats. Topography of the site, soil conditions, and depth of soil above bedrock are factors influencing not only the location, but type of ground mat used. Some common types (in addition to forebay location) are:

(1) Ground rods driven to permanent moisture and interconnected by a grid system of bare, soft annealed copper conductors. This type of mat is preferable.

(2) A grid of interconnected conductors laid in trenches dug to permanent moisture below the frost line.

(3) Ground wells with steel casings used as electrodes, or holes in rock with inserted copper electrodes and the hole backfilled with bentonite clays. The wells or holes should penetrate to permanent moisture.

(4) Plate electrodes or grids laid in the powerhouse tailrace, suitably covered or anchored to remain in place.

e. Ground resistance test. A test of the overall project ground resistance should be made soon after construction. Construction contract specifications should contain provisions for adding ground electrodes if tests indicate that this is necessary to obtain the design resistance. Proper measurement of the resistance to ground of a large mat or group of mats requires placement of the test electrodes at a considerable distance (refer to IEEE 81). Transmission line conductors or telephone wires are occasionally used for test circuits before the lines are put into service.

13-5. Powerhouse Grounding

a. Main grounding network.

(1) This network should consist of at least two major runs of grounding conductors in the powerhouse. Major items of equipment such as generators, turbines, transformers, and primary switchgear should be connected to these grounding "buses" so there are two paths to ground from each item of equipment.

(2) Copper bar rather than cable is preferred for exposed runs of bus. Generator leads of the metal-enclosed type will be equipped by the manufacturer with a grounding bar interconnecting all bus supports. Properly connected, this forms a link in the powerhouse ground bus.

(3) In selecting conductor sizes for the main grounding network, three considerations should be borne in mind:

(a) The conductors should be large enough so that they will not be broken during construction.

(b) Current-carrying capacity of the conductors should be sufficient to carry the maximum current for a fault to ground for a minimum period of 5 sec without damage to the conductor (fusing) from overheating.

(c) The total resistance of the loads from major items of equipment should be such that the voltage drop in the cable under fault conditions will not exceed 50 V.

b. Equipment. Miscellaneous electrically operated equipment in the powerhouse should be grounded with taps from the main ground network. For mechanical strength, these conductors should be not less than No. 6 AWG. The resistance of these taps should keep the voltage drop in the leads to the ground mat to less than 50 V. They should carry the current from a fault to ground without damage to the conductor before the circuit protective device trips. Provisions should be made in the design of the powerhouse grounding system for bare copper cable taps of sufficient length to allow connection to equipment installed after installation of the grounding system. Generally, the tap connection cable is coiled in a concrete blockout for easy accessibility later when attaching the tap to the housing of the equipment with pressure connectors. Items of minor equipment may be grounded by a bare wire run in the conduit from the distribution center to the equipment. The neutrals and enclosures of lighting and station service power transformers should be grounded. Distribution center and lighting panel enclosures as well as isolated conduit runs should be grounded.

c. Conductor size selection. Ground conductor sizes should be limited to Nos. 6, 2, 2/0, 250 kCM and 500 kCM, or larger, to limit ordering inventories and access normally stocked conductor sizes. Subject to short-circuit studies, usage, in general, is as follows:

(1) No. 6: Control cabinets, special outlets, machinery, lighting standards, power distribution equipment with

main feeders #2 or less, and motor frames of 60 hp or less.

(2) No. 2: Switchboards, governor cabinets, large tanks, power distribution equipment with primary or secondary feeders 250 kCM or less, and motor frames between 60 and 125 hp.

(3) No. 2/0: Roof steel, crane rails, generator neutral equipment, gate guides, power distribution equipment with primary or secondary feeders larger than 250 kCM, and motor frames larger than 125 hp.

(4) 250 kCM: Turbine stay-rings, turbine pit liners, generator housings and/or cover plates, large station service transformers, transmission tower steel, and interconnecting powerhouse buses.

(5) 500 kCM: Main powerhouse buses, leads to the ground mat, generator step-up transformer grounds, and surge arrester grounds.

(6) 750-1,000 kCM: Main powerhouse buses or leads to the ground mat when larger sizes are needed.

d. Miscellaneous metal and piping. Powerhouse crane rails should be bonded at the joints with both rails being connected to ground. Roof trusses; draft tube gate guides; and miscellaneous structural steel, which may be exposed to dangerous potentials from energized circuits, should be connected to the ground network. All piping systems should be grounded at one point if the electrical path is continuous, or at more points if the piping system's electrical path is noncontinuous.

13-6. Switchyard Grounding

a. Copper conductors. A grid of copper conductors should be installed beneath the surface of the switchyard to prevent dangerous potential gradients at the surface. The cables should be large enough and be buried deep enough for protection from mechanical damage. The cables' current-carrying capacity under fault conditions and during lightning discharges should be checked. Under all conditions, the grid serves to some extent as an electrode for dissipating fault current to ground.

b. Ground rods. If warranted by soil conditions, a system of ground rods should be installed with the grid to provide maximum conductance to ground.

c. Grounding platform. A grounding platform consisting of a galvanized steel grating set flush in the gravel

surfacing or a grounding mesh buried 12-18 in. below grade should be provided at each disconnecting switch handle. The platform or mesh should be grounded to the steel tower and to the ground network in two places.

d. Grounded equipment. Grounded switchyard equipment includes tanks of circuit breakers, operating mechanisms of disconnecting switches, hinged ends of disconnect grounding blades, transformer tanks and neutrals, surge arresters, cases of instrument transformers and coupling capacitors, and high-voltage potheads. Isolated conduit runs, power and lighting cabinet enclosures, and frames of electrically operated auxiliary equipment should also be grounded. Separate conductors are used for grounding surge arresters to the ground network. Fences, including both sides of any gates, and other metal structures in the switchyard, should be grounded to the switchyard grid at intervals of about 30 ft. If the fence gates open outward, a ground conductor shall be provided approximately 3 ft outside the gate swing radius. Each switchyard tower should be grounded through one leg. All structures supporting buses or equipment should be grounded. If the network does not extend at least 3 ft outside the fence line, separate buried conductors should be installed to prevent a dangerous potential difference between the ground surface and the fence. These conductors should be connected to both the fence posts and the ground network in several places.

e. Overhead ground wires. Overhead ground wires should be bonded securely to the steel structure on one end only and insulated on the other to prevent circulating current paths.

13-7. Grounding Devices

a. Cables. Grounding cable used for direct burial or embedding in concrete should be soft-drawn bare copper. Sizes larger than No. 6 AWG should be stranded.

b. Electrodes. Electrodes for driving should be copper-weld rods of appropriate diameter and length. Desired lengths can be obtained on factory orders.

c. Exterior connections. Ground cable connections to driven ground rods, any buried or embedded connections, or any exposed ground grid connections should be made either with an appropriate molded powdered metal weld or by a copper alloy brazed pressure connector.

d. Interior connections. Pressure clamp (bolted) type terminal lugs should be used for interior work. For neatness of appearance of interior connections, embedded

grounding cables may terminate on or pass through grounding inserts installed with the face of the insert flush with the finished surface. Connection to the apparatus is made by bolting an exposed strap between a tapped hole on the insert and the equipment frame.

e. Test stations. Test stations should be provided for measuring resistance of individual mats and checking continuity of interconnecting leads. Where measurements are contemplated, the design of the grounding systems should avoid interconnection of ground mats through grounded equipment, overhead lines, and reinforcing steel.

f. Embedded cable installation. Embedded ground cables must be installed so movement of structures will not sever or stretch the cables where they cross contraction joints. Suitable provision should be made where embedded cables pass through concrete walls below grade or water level to prevent percolation of water through the cable strands.

g. Conduit. Grounding conductors run in steel conduit for mechanical protection should be bonded to the conduit. Control cable sheaths should be grounded at both ends. Signal cable shields are grounded at one end only.